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Agricultural Memorandum No. 1067

Straw Burning Smut Dispersion Model: Modifications and Verification

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SUMMARY

This paper is a sequel to Agricultural Memorandum No. 1014 which describes the downwind dispersion of smuts and smoke from a straw fire. In this memorandum various modifications to the model are described, notably lateral dispersion, the introduction of field size sources with the associated movement of the flame front within the field as the burn progresses, and the introduction of a smut fall speed spectrum as a function of smut mass.

The model data have been compared with data from field experiments, but since current field data still lack precision, objective verification of the model remains a problem. The comparisons carried out so far indicate that there is no great discrepancy between the model and reality. Further model modifications and enhancements will be held in abeyance until more accurate field measurements become available.

1. Introduction

Lee (1985) described a model for estimating the downwind deposition of smuts and the downwind concentration of smoke from straw fires. Since then field trial data have been analysed (Larkin et al (1985)), and data on burn rate and wind direction variability, for instance, have been included in the model. The model has also been extended to cover lateral as well as downwind smut dispersion, so that plans of the downwind smut deposition patterns can be produced by contouring the smut deposition densities.

The data from the field trials have provided a means of verifying certain aspects of the model. However, the measurements of smut output and deposition are of poor quality, due to insufficient sampling of processes that over the duration of the burn are often inhomogeneous in both space and time. This created a need for many assumptions, for instance about the length of time the plume was blowing over a particular sampling device. Further uncertainty is caused by unanswered questions about the collection efficiency of some of the samplers. The net result is that estimates of smut output in particular vary over wide ranges for the same burn, depending upon the sampling device used.

2. Changes to the Model

2.1 Vertical Dispersion (σ_z) - Lee (1985) used theoretical values of vertical plume dispersion given by Hosker (1974). Since then measurements of actual plume dispersion taken from photographs and video films have been compared with the theoretical values. The presence of turbulence within the plume, generated by shearing action between the plume and the ambient air causes the observed values of σ_z to be about a factor of two larger than the theoretical values close

to the source, taking σ_z to be the distance from the plume centre to the observable limit. Once the plume has become neutrally bouyant it will have lost its internal turbulence and further expansion will depend upon the prevailing atmospheric turbulence alone. The implication therefore is that the rate of change of σ_z is partly related to the updraught and partly to the prevailing atmospheric turbulence.

The updraught is not a simple term to measure directly, but can be inferred from the angle of plume rise and the wind speed. Assuming the wind speed to be constant with height (as it is in the model) the following equation will account for the observed increases in σ_z resulting from the internal turbulence of the plume.

$$\delta\sigma_z^* = \delta\sigma_z \left(1 + \frac{\tan\alpha}{\tan\alpha_0}\right)$$

Where $\delta\sigma_z^*$ = Change in vertical dispersion coefficient that has been enhanced by internal turbulence.
σ_z = Change in theoretical dispersion coefficient.
α = Mean angle of plume rise over the time step
α_0 = Initial plume rise angle

This relationship implies that the initial increase in σ_z will always be by a factor of 2 irrespective of the updraught. In the absence of an absolute updraught v σ_z relationship this is the best that can be achieved. Sensitivity tests show that a factor of two change in σ_z does not significantly alter the smut deposition pattern, and so minor discrepancies in the size of σ_z are acceptable within the model's overall error margins.

2.2 Lateral Dispersion (σ_y) - Two mechanisms govern lateral dispersion: turbulent diffusion within the plume (σ_{yt}) and meandering of the whole plume due to wind direction variations (σ_{yw}) giving

$$\sigma_y^2 = \sigma_{yt}^2 + \sigma_{yw}^2 \qquad (2)$$

The turbulent diffusion component is a function of distance from the source, atmospheric stability, and the internal turbulence of the plume. The wind direction variation is a function of the elapsed time, wind speed and atmospheric stability.

Figure 1 (from Clarke (1979)) shows the turbulent components of the plume dispersion assuming that there is no excess turbulence within the plume over and above that within the ambient air. In section 2.1 it has been explained that this relationship is altered in the straw burning situation due to internal plume turbulence. Because turbulence cannot be limited to a single direction, turbulence within the plume will affect σ_{yt} as well as σ_z. Hence the following equation analogous to equation (1) is used to derive the actual turbulent diffusion from the theoretical value, even though no direct observations have been made.

$$\delta\sigma_{yt}^* = \delta\sigma_{yt} \left(1 + \frac{\tan\alpha}{\tan\alpha_0}\right) \qquad (3)$$

The component of lateral spread attributed to wind direction variations (σ_{yw}) was assumed to follow the empirical form used by Fisher and Moore (1979).

$$\sigma_{yw} = ax\sqrt{\frac{T}{u}} \qquad (4)$$

Where σ_{yw} = arc of lateral spread (m)
T = burn time (minutes)
u = wind speed (m/sec) at 8 m
x = distance from source (m)

The coefficient a was evaluated as 0.085 from the 1984 Straw Burning Trial data. σ_{yw} is generally much greater then σ_{yt}. The only exception to this rule occurs for a burn lasting less than ten minutes in breezy conditions.

2.3 Movement Of the Flame Front - For the purpose of modelling no account is taken of the initial period required to produce the flame front or the death throes of the fire when a wide variety of burning patterns and intensities will be present, but for a relatively short and insignificant period of time. For the majority of the burn period the fire's progress is almost a steady state providing the wind speed does not change. So in order to simulate the burning of the entire field it is only necessary to perform the dispersion calculations once for an instantaneous flame front, and move the downwind deposition pattern around in a way appropriate for the burn rate and field size, as the flame front moves across the field. The smut deposition at any point is then the accumulated deposit for all flame-front positions.

When burning with or against the wind a certain proportion of the smuts will fall on the field. In most conditions only a small proportion of the smuts leaving a burn made with the wind from a standard shape of field actually fall back on to the field again, and so errors caused by not accounting for relifting would be minimal. When burning against the wind all smuts fall on to previously burnt ground and so relifting would not occur as a result of the burning process.

2.4 Smut Spectrum - In previous work it was assumed that all smuts fall at the same velocity. However this has been shown not to be the case. A fall speed spectrum, assumed to be Gaussian in terms of smut numbers with a mean of 0.8 ms^{-1} and standard deviation of 0.3 ms^{-1} has been observed in the laboratory (Spanton et al 1984). In field experiments it is the mass rather than the number of smuts that is recorded, and so to make meaningful comparisons with the model the fall speed spectrum as a function of mass needs to be used, even though it may be the quantity of smuts that actually determines the public nuisance factor.

Work by Mason (1971) on falling ice crystals and particularly ice needles, which like straw have one elongated dimension, indicates that the relationship between fall speed and mass is far from linear, being something greater than a squared relationship. Consequently the fall speed spectrum as a function of mass rather than quantity becomes skewed towards higher fall velocities as shown in Figure 2, with a peak mass deposition for a fall speed of 1.1 ms^{-1} rather than 0.8 ms^{-1}. It is this spectrum that is incorporated into the model, being the best that can be achieved based on current information.

3. Field Trial Information

During the field trials carried out in the Summer of 1984 (see Larkin et al, 1985) much useful information was gleaned. From the observations, equations relating the flame front speed (sff) and depth (dff)to burn type and wind speed were derived. The relationships are shown in Figure 3 . The scatter in the data in Figure 3 indicates that wind speed is not the sole driving force behind the flame speed; straw moisture, straw type and straw treatment (swathed, spread or chopped) will also have a role especially when burning against the wind. However, for modelling purposes sff was assumed to be dependent on wind alone. When burning across the wind the speed of the flame front is regulated by the person carrying out the burn. A value of about 1 m per 10 seconds is about average but other speeds between 1 metre per 60 seconds and 1 metre per 5 seconds were investigated using the model.

During the field trials estimates of smut output from any one fire ranged from 5 to 250 kg per hectare; in the model a value of 50 kg per hectare has been used.

Other data obtained from the field trials such as deposition quantities, plume height and updraughts, were of use in model verification and will be discussed later.

4. Method and Results

In order to determine the effects of the initial conditions upon the smut deposition regime, one initial condition parameter was altered whilst the others were kept constant within the model. The initial conditions that can be altered are as follows:-

i) Burn method - with, against or across (that is in line with) the wind.

ii) Wind speed.

iii) Thermal atmospheric stability, expressed in terms of lapse rate.

iv) The size and shape of the field defined by width and depth.

v) The smut output from the fire.

vi) For burning across the wind only, the manual drag speed of the flame front.

In Tables 1-3 the effects on plume height, burn rate and smut deposition are shown when the parameters are altered one by one.

Figures 4-6 give plan views of the smut deposition patterns from the three types of fire in what could be considered as typical summer conditions, that is moderately unstable conditions with a 3 ms^{-1} wind. The deposition is symmetrical about a line bisecting the field so only half the pattern is shown. In the absence of any quantitative data the impact of the various smut densities upon the community that is shown in Table 4 can only be inferred from the smut densities observed during field trials. Work in this area is needed in order to apply more rationally the information given by model data.

TABLE 4: Speculated relationship between smut deposition and 'nuisance' value.

Smut deposition density (mgm^{-2})	Effect
0.1	Only causes a nuisance to sensitive industries, hospitals etc.
1.0	Nuisance to washing and wet paint
10.0	Causes nuisance within home.
100.0	Gives a light sprinkling, unacceptable to all the populace.

5. Discussion

5.1 Burn Method - In the most simplistic terms there are three possible ways in which a field may be burnt; with, against or across the wind. When burning with the wind, a strip along the upwind edge of the field is lit and the flame front is then allowed to move quickly across the field aided by the wind. The burn is vigorous and the flame front is wide. A burn against the wind is started at the downwind edge and the front slowly moves into the wind. Such a burn is quiet with a narrow flame front, takes a long time to complete and in high wind speeds may be impossible to sustain. A burn made across the wind has to be constantly tended in order to keep a relatively narrow flame front burning in line with the wind, this is done by manually moving the windward edge of the flame front across the field with a pitchfork. In order for a burn across the wind to succeed the wind direction has to be relatively constant and so normally it can only be carried out successfully at the higher permissible wind speeds.

The time taken to burn a field against the wind is very long (up to several hours) with the smuts being deposited almost uniformly around all sides of the field except the upwind edge, as shown in Figure 4. The smuts are not carried very far because of the weakness of the updraught, causing over 80% of the smuts to be deposited within the burn area. Nevertheless within the first few metres of the field edge the deposition densities at any point are 5 to 10 times as high as they are for the other burn types.

The smut deposition patterns from burns made with or across the wind are very similar (Figures 5 and 6), but the smuts from burns made across the wind travel slightly less far than those from burns made with the wind in identical conditions. As a result of this, the burn made across the wind has a higher peak deposition density.

5.2 Wind Speed - it can be seen from Table 1-3 that for all three burn types an increase in wind speed increases the downwind distance to which smuts are carried. As well as determining the horizontal

velocity of the smuts, the wind speed has an effect upon the plume which in turn helps to determine smut transportation distances, by changing:-

i) the heat output.

ii) the plume height.

iii) both vertical and lateral dispersion.

Heat output is proportional to burn rate which is in turn partly dependent on wind speed. An increase in the heat output produces a more buoyant plume which rises higher. When burning with the wind burn rate and hence heat output increase with wind speed, enhancing plume rise and downwind smut transport. When burning against the wind, the burn proceeds at an ever slower pace as the wind increases, reducing plume rise and downwind smut transport. When burning across the wind the burn rate is manually constrained and so wind speed has no effect upon heat output in theory and only increases marginally with wind speed in reality.

As a result of increased vertical dispersion and increased entrainment of ambient air in higher wind speeds there is a tendency for buoyancy to be lost and hence for a reduction in plume rise to occur (Lee (1985)). When burning with the wind this property and the effect of heat output are in opposition, but the latter holds the ascendency with plume rise actually increasing with wind speed. When burning across the wind, in the absence of heat output changes, plume rise is reduced as wind speed increases. When burning against the wind the effects of dispersion and heat output are additive giving rise to significant reductions in plume rise as wind speed increases.

An increase in wind speed causes an increase in vertical dispersion which has two opposing effects on smut transport. On the one hand it allows smuts to rise higher and hence be carried further but on the other hand it dilutes the plume reducing the density of smuts both in the air and on the ground. It is the dilution effect that makes any increase in downwind smut transport very small when burning across the wind in higher wind speeds, because dispersion is reducing the smut concentrations to unmeasurable quantities almost as fast as the wind is pushing smuts further downwind. The same principle applies to a lesser degree to the other two burn methods.

The increased lateral spread is a result of the larger smut transportation distance in higher winds and not due to turbulent causes, as σ_y decreases as the wind speed increases.

Compared with the other two burn types the manual constraint on burn rate when burning across the wind considerably reduces the effect of wind speed on smut deposition densities and distances, with only a doubling in the maximum deposition distance for an increase in windspeed from 1 to 6 ms^{-1}, and deposition densities remaining approximately constant.

When burning with the wind the wind speed has most impact on both deposition densities and deposition distances at low wind speeds since this is when plume rise and dispersion are affected most.

The smut deposition pattern produced by burns made against the wind is influenced considerably by large changes in the mass of smuts leaving the field as the wind speed alters, with many more smuts leaving the field in high wind speeds. This is because most smuts are deposited within a few tens of metres of their source which is generally less than the field depth. Consequently as the wind speed increases many more smuts remain airborne for long enough to leave the field causing the maximum deposition density to increase as well as the distance to which smuts are carried, a phenomenon not present in the other two burn types.

5.3 Atmospheric Lapse Rate - The lapse rate, being a measure of the way in which temperature varies with height, affects both plume height and plume dispersion. A stable lapse rate reduces plume height and dispersion, an unstable lapse rate increases plume height and dispersion. As instability increases, the net effect on all burn types is to increase the distance to which smuts are transported both downwind and laterally. For burns made with and across the wind the increased area covered by smuts necessarily implies a reduction in the peak deposition densities since there is no change in the mass of smuts leaving the field. However, when burning against the wind the maximum deposition densities remain roughly constant. This is because of the changes in the mass of smuts leaving the field as the transport distance changes, as described in the previous section, are almost balanced by dispersion changes. The net effect is to produce a minimum in deposition density in neutral lapse rate conditions.

In the model lapse rate is invariant over the entire plume height, in reality this would not occur at the extremes of stability and instability. This implies that the actual deposition distances in these conditions may not be as short or long respectively as those given in Tables 1-3.

5.4 Field Shape - Compared with wind speed and stability the effect of field shape on the smut deposition pattern is small. When burning with or against the wind changes in field shape, and hence the length of the flame front, do not affect the height to which the plume will rise or the distance to which a smut will be carried, unless the flame front is very narrow. This is because once the flame front width is about ten times the front depth, the source has become sufficiently elongated for increases in bulk buoyancy, the primary factor which determines plume height, to be negligible. At a wind speed of three metres per second the flame front for a burn made with the wind is about 12 metres deep and so once the flame front width has exceeded about 120 metres, buoyancy and plume height remain unchanged. For burns made against the wind the dimensions are reduced to 0.2 and 2 metres respectively. And so in the examples given in the tables, the only situations where changes in plume height have arisen as a result of changes in bouyancy, occur for burns made with the wind when the flame front is narrow.

The reason for the increase in smut deposition distance with increasing flame front width therefore has to be attributed to another cause, namely the effect of dispersion. When considering fields of the same total area, an increase in the flame front width is countered by a corresponding decrease in the other dimension of the field, reducing the time taken to carry out the burn, and hence the lateral dispersion. Also, for a wide flame front the initial plateau area of peak smut deposition density which has to be eroded away will be wide, and so the erosion will take longer and the plume be transported

farther than if the flame front was narrow, as shown schematically in Figure 7. The combined effect is for deposition densities to remain higher further downwind, giving the impression of smuts being carried further, when a smut deposition density of .01 mgm^{-2} is taken as the measurable limit.

When considering burns made across the wind slightly different principles apply. When burning with or against the wind as soon as the buoyant parcel of air leaves the source it is free from external forcing, but when burning across the wind, the parcel may pass over up to several hundred metres of additional heat (and buoyancy input) causing the top surface of the plume to rise higher. It is this phenomenon that gives rise to the somewhat greater effect that changing the flame front length has on the downwind transport when burning across the wind than is found in the other burn types.

For all these burn types the lateral dispersion increases with the burn time, which is dependent upon the field shape.

Since the downwind area covered by smuts varies little for all field shapes within a particular burn type it is not surprising that the peak deposition densities also vary little. When burning against the wind there is no change at all since the smut deposition distances are normally on a smaller scale than the field shape changes.

5.5 Field Size - When considering the effect of field size on smut deposition the same principles as those governing the field shape relationships broadly apply. However inspection of the model output shows that field size does affect the smut deposition much more than changes in field shape and so other factors must be working in addition to those given above. The primary additional factor is that the total mass of smuts given off and hence deposited increases with field size. When dispersed over the downwind area these extra smuts have the effect of pushing the maximum smut deposition (0.01 mgm^{-2}) distance further out, in the manner shown in Tables 1-3.

For burns made across and with the wind the same integration effect serves to increase the maximum deposition density markedly as the field size increases, but with the increase tailing off at the larger field sizes where a large increase in area is accompanied by only small increases in the field dimensions.

5.6 Drag Speed - It is only burns made across the wind that can have their speed of propagation altered manually by varying the speed at which the front is dragged across the field perpendicular to the wind direction. Fast drag speeds are accompanied by fast burns, increased buoyancy and increased distance to which smuts are carried. This is accompanied by a corresponding decrease in the maximum smut density and an increase in the distance away from the source that it occurs.

6. Comparison of Model and Field Data

6.1 Smut Deposition - Measurements made in the 1984 Field Trials have been compared with the model. Most fields were burnt using a combination of burning against the wind and one of the other two methods (brief details of each burn are given in Appendix 1). Consequently the model runs had to be split up into appropriate sections and the results added together. The smut output used in the model, taken as ten times that given by the most conservative sampling method, conforms with the analysis in the previous section. The field and model data are given in Table 4, together with the ratio of the

two. The ratio gives a more realistic assessment of how well the model is performing bearing in mind the lack of precision in the field data.

These ratios give an indication that the model is most in error when most or all of the field is burnt against the wind, such as in burns 201 and 204, when the ratio drops rapidly with distance from the source. This implies that the smuts are being deposited by the model too close to the source. However, burn 215 which also had a high proportion of backburning does not display this effect.

The actual deposition densities normally display random changes about a constant level rather than the fall off with distance shown by the model; probably caused by changes in windspeed during the burn and changes in the windspeed and atmospheric stability with height, factors not taken into account by the model.

6.2 Updraught and Plume Height - These are two parameters produced by the model; both can, with difficulty, be quantified by observation. The updraught decreases very rapidly close to the source and can be obscured by random eddy movement within the plume, but can be inferred from the windspeed and angle of plume rise. The plume height can only be reliably judged when there is sufficient smoke present for it to remain visible at higher altitudes after significant dilution. During the 1984 trials, on two occasions cumulus cloud formed on top of the smoke plume, but on neither occasion would the plume have been judged visually to have reached such an altitude were it not for the clouds. The very fact of cloud formation indicated that at this altitude (about 600 m) the plume still contained considerable buoyancy.

Subjective estimates of the initial updraught from burns made with or across the wind were of the order of 10 ms^{-1}. The updraught figures compare favourably with those gained from the model which are usually higher at 15 to 25 m per second. A rapid decrease in updraught is then observed both in the model and in the field. For burns made against the wind the observed and model figures are about 1 ms^{-1} and 0.5 ms^{-1} respectively, indicating a systematic though not particularly significant underestimate in absolute terms by the model for this burn type.

Field observations of plume height for burns made with and across the wind varied widely but were in the region of 200-1000 m, with the average across wind plume height the slightly lower of the two. Such values are up to four times lower than those predicted, not unreasonable considering the observational difficulties as the plume becomes more diffuse. The theoretical values for plume height when burning against the wind are very similar to the observed values, and so bearing in mind the observational difficulties, indicate that the model may not be lifting the plume quite high enough. This is in agreement with the updraught data, both indicating that model burns against the wind are 'weaker' than the reality.

6. Conclusions

One of the primary objectives when straw burning is to reduce to a minimum the distance downwind to which smuts can be transported. Whatever the weather conditions, this will always be achieved most readily when burning against the wind. However, strong winds, damp straw, straw treatment and burn time may either singly or in combination prevent a burn

being made against the wind. Assuming that fields larger than 10 hectares in area cannot be burnt and that burning during darkness is not allowed, then the following minimum smut transport distances can be achieved.

Type	Wind Speed	Field Width	Field Depth	Burn Time	Smut Travel
Against	2 ms^{-1}	1000 m	100 m	1 h 34 m	600 m
With	2 ms^{-1}	100 m	1000 m	1 h 23 m	5400 m
Across	3 ms^{-1}	1000 m	100 m	2 h 47 m	6300 m

If burning were allowed after dark, and especially if burning were to be carried out around dawn on quiet anticyclonic mornings, the maximum distances to which smuts would be transported would be reduced to 75 m for burns against the wind, 1400 m for burns with the wind and 5000 m for burns made across the wind. However, at this time of day in anticyclonic weather the winds would be light and so variable that the burn might be difficult to control.

A wind speed of at least 3 ms^{-1} is needed for the wind direction to remain sufficiently constant for a burn across the wind to be carried out. This immediately makes across wind burning unattractive when the minimum possible smut deposition distances are being considered. Conversely in high wind speeds, across wind burning becomes increasingly attractive, with maximum smut deposition distances about 15-20% lower than those from burns made with the wind in a 6 ms^{-1} wind speed, in this wind burning against the wind would be impractical, if not impossible.

Once the flame front width has exceeded about 10 times the flame front depth, a further extension of the flame front width will have very little effect upon plume height and the distance downwind to which smuts are deposited, when burning with or against the wind. For a burn against the wind this criterion is met with even the shortest of flame fronts, and so when burning in this manner the width of the flame front should be made as long as possible to enable as fast a burn as possible to take place, without fear of smuts being transported over larger distances. When burning with the wind, in very light winds the same principle applies as for burning against the wind. However, in winds of 3 ms^{-1} and more there is benefit in keeping the flame front width to less than 100 m.

For burns made across the wind the flame front should be kept as short as possible to reduce downwind smoke dispersion, because of the constant bouyancy input into the plume so long as the plume remains over the heat source of the flame front. And so unless a field is being burnt against the wind or burnt with the wind in light winds there is some merit in keeping the flame front as short as possible. This can be achieved by dividing the field into elongated strips and burning either with or across the wind as appropriate to give the shortest flame front for the prevailing wind direction. If back burning or burning in light winds there is no merit in dividing the field into 10 hectare strips, but proceeding to burn the whole area with as long a flame front as possible. This is said with the proviso that the field could not be split up and each strip burnt on, say, consecutive days, when the wind direction will change allowing the smuts to be dispersed over a larger area.

In the event of a sensitive area lying immediately downwind of the burn and a change in wind direction cannot be waited for, then, if the conditions are suitable, a burn across the wind will give the least pollution over the first few hundred metres downwind. Back burning should be most definitely avoided, necessitating larger fire breaks than normal.

The possible scenarios that could be considered are legion, and would need to be dealt with individually. But overriding any situation is one clear factor and that is that smuts have to go somewhere, making one man's gain another man's loss whatever burning policy is adopted. A further complication, as explained in Lee (1985), is that conditions favouring reduced smut pollution often give rise to bad smoke pollution and vice versa. When straw burning one most definitely cannot 'please all the people all the time'.

7. References

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KEY WORDS: Straw Burning, Dispersion Modelling.

Any comments or suggestions on this paper should be referred to the author.

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TABLE 1: BURNS MADE WITH THE WIND.

		MAX. DEP. DENS ($mg m^{-2}$)	DIST. OF MAX. DENS (m)	MAXIMUM DISTANCE (m)	MAX LATERAL DIST (m)	>100 $mg m^{-2}$ FROM (m)	>100 $mg m^{-2}$ TO	>10 $mg m^{-2}$ FROM (m)	>10 $mg m^{-2}$ TO	>1 $mg m^{-2}$ FROM (m)	>1 $mg m^{-2}$ TO	PLUME HEIGHT (m)	BURN TIME
WIND SPEED ms^{-1}	1	306	0	3100	2150	0	150	0	400	0	750	700	1h 23
	3	41	800	18000	5450	—	—	0	1850	0	2950	1750	0h 28
	6	8	2600	30500	6100	—	—	—	—	0	6550	1800	0h 14
LAPSE RATE OC $100m^{-1}$	0.1	17	0	18550	6400	—	—	0	2000	0	4150	1900	0h 28
	0.3	41	800	18000	5450	—	—	0	1850	0	2950	1750	0h 28
	0.5	89	500	14400	4950	—	—	0	1550	0	2350	1000	0h 28
	0.9	149	400	10700	4350	100	650	0	1450	0	2750	750	0h 28
	1.2	223	300	8600	3850	0	600	0	1200	0	2350	650	0h 28
FIELD SHAPE WIDTH/DEPTH	100/1000	37	400	17200	6275	—	—	0	1450	0	2550	1700	0h 56
	200/500	41	800	18000	5450	—	—	0	1850	0	2950	1750	0h 28
	300/333	44	900	18600	5050	—	—	0	1960	0	3050	1750	0h 19
	500/200	44	1000	18900	4700	—	—	300	1950	0	3150	1750	0h 11
FIELD SIZE	1	6	1000	12400	1500	—	—	—	—	0	2050	1700	0h 06
	4	20	1000	15800	3625	—	—	0	1600	0	2800	1750	0h 11
	10	44	900	18600	5050	—	—	0	1950	0	3050	1750	0h 19
	25	92	900	21400	6650	—	—	0	2450	0	4150	1750	0h 28
	49	148	700	23300	8150	300	1250	0	2600	0	4700	1750	0h 39

TABLE 2: BURNS MADE AGAINST THE WIND.

		MAX. DEP. DENS ($mg\,m^{-2}$)	DIST. OF MAX. DENS (m)	MAXIMUM DISTANCE (m)	MAX LATERAL DIST (m)	>100 $mg\,m^{-2}$ FROM (m)	TO	>10 $mg\,m^{-2}$ FROM (m)	TO	>1 $mg\,m^{-2}$ FROM (m)	TO	PLUME HEIGHT (m)	BURN TIME
WIND SPEED ms^{-1}	1	568	0	580	575	0	16	0	19	0	50	200	5h 33
	3	609	0	3100	2000	0	18	0	35	0	210	170	9h 37
	6	706	0	4700	2800	0	24	0	140	0	440	155	13h 36
LAPSE RATE OC $100m^{-1}$	0.1	660	0	4500	2600	0	19	0	120	0	320	295	9h 37
	0.3	609	0	3100	2000	0	18	0	35	0	210	170	9h 37
	0.5	603	0	1950	1400	0	17	0	19	0	110	160	9h 37
	0.9	614	0	1080	580	0	17	0	19	0	60	150	9h 37
	1.2	611	0	510	450	0	16	0	19	0	40	130	9h 37
FIELD SHAPE WIDTH/DEPTH	100/1000	608	0	2500	2000	0	17	0	34	0	160	170	19h 15
	200/500	609	0	3100	2000	0	18	0	35	0	210	170	9h 37
	300/333	610	0	3400	1900	0	18	0	35	0	220	170	6h 25
	500/200	609	0	3600	1850	0	17	0	34	0	225	170	3h 51
FIELD SIZE	1	607	0	1800	675	0	17	0	32	0	110	170	1h 55
	4	608	0	2600	1325	0	18	0	35	0	180	170	3h 51
	10	610	0	3400	1900	0	18	0	35	0	220	170	6h 25
	25	609	0	4200	1325	0	17	0	37	0	270	170	9h 37
	49	609	0	4950	3400	0	14	0	36	0	300	170	13h 29

Table 3: Burns Made Across The Wind

		Max. Dep. Dens ($mg.m^{-2}$)	Dist. of Max. Dens (m)	Maximum Distance (m)	Max Lateral Dist (m)	>100 $mg\,m^{-2}$ From (m)	>100 $mg\,m^{-2}$ To	>10 $mg\,m^{-2}$ From (m)	>10 $mg\,m^{-2}$ To	>1 $mg\,m^{-2}$ From (m)	>1 $mg\,m^{-2}$ To	Plume Height (m)	Burn Time
Wind Speed ms^{-1}	1	75	900	8600	4300	—	—	10	1850	0	2950	1750	0h33
	3	110	600	15900	4700	550	700	10	1650	0	2950	1500	0h33
	6	112	600	17400	3550	550	650	0	1800	0	3400	1100	0h33
Lapse Rate or $100m^{-1}$	0·1	41	600	16000	4950	—	—	0	1950	0	3550	2100	0h33
	0·3	110	600	15900	4700	550	700	10	1650	0	2950	1500	0h33
	0·5	162	500	12200	4300	450	950	20	1550	10	2750	1300	0h33
	0·9	230	700	8500	3900	350	800	30	1350	10	2450	1000	0h33
	1·2	439	400	7600	3900	250	750	100	1250	10	2250	800	0h33
Field Shape Width/Depth	100/1000	70	700	17600	4500	—	—	0	2050	0	3250	1650	0h17
	200/500	110	600	15900	4700	550	700	10	1650	0	2950	1500	0h33
	300/333	110	600	14400	4900	550	700	40	1650	0	2450	1350	0h50
	500/200	102	500	13000	5200	500	500	10	1350	0	1750	1150	1h23
Field Size	1	34	400	7500	1600	—	—	150	750	0	1300	1100	0h17
	4	65	500	11500	3270	—	—	60	1100	0	1800	1300	0h33
	10	110	600	14400	4900	550	700	40	1650	0	2450	1400	1h07
	25	178	600	17500	7200	500	1000	10	1950	0	3050	1500	1h23
	49	218	700	20100	9200	450	1200	0	2350	0	3950	1550	1h56
Drag Speed sm^{-1}	5	64	700	17500	4550	—	—	0	2150	0	3050	1650	0h17
	10	110	600	15900	4700	550	700	10	1650	0	2950	1500	0h33
	30	174	300	12600	5100	250	650	0	1250	0	2150	1400	1h40
	60	201	200	10800	5300	100	450	0	1000	0	1750	1150	3h20

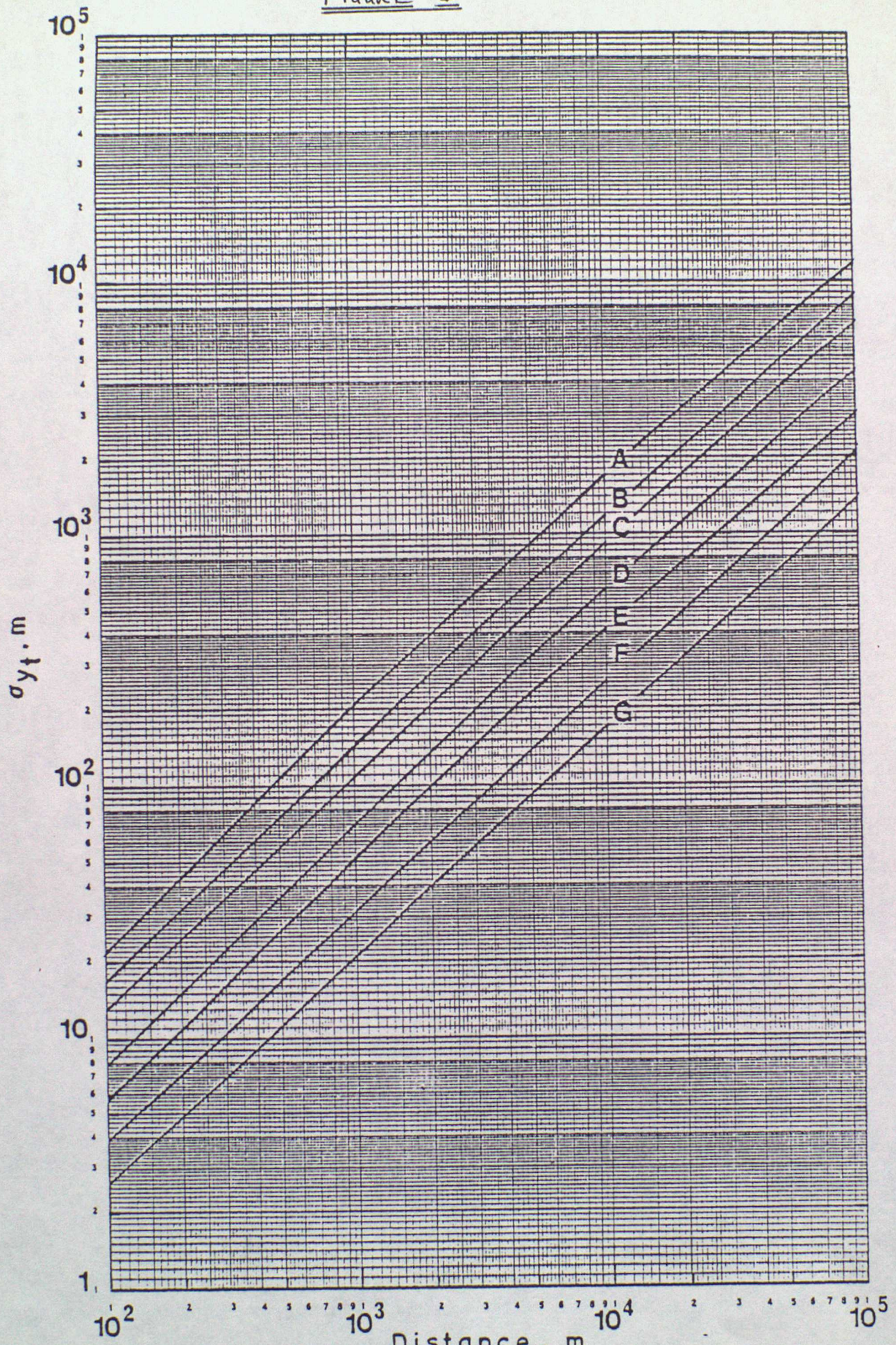
TABLE 4: FIELD MEASURMENTS AND MODEL ESTIMATES OF SMUT DEPOSITION ($mg\ m^{-2}$)

BURN NUMBER	Z01		Z02		Z03		Z04		Z05		Z08		Z15	
DISTANCE DOWNWIND	F	M	F	M	F	M	F	M	F	M	F	M	F	M
10m	250	1170	/	/	/	/	510	780	560	570	690	1400	2450	5900
30m	330	410	290	1030	440	80	470	80	430	565	/	/	/	/
50m	270	140	/	/	/	/	/	/	/	/	640	345	610	2140
100m	300	45	350	1070	/	/	430	8	380	555	680	380	570	2120
200m	240	40	290	820	250	75	370	4	390	665	640	520	500	2130
500m	/	/	330	750	180	75	/	/	/	/	/	/	450	2100

RATIO M/F

	Z01	Z02	Z03	Z04	Z05	Z08	Z15
10m	4·7	/	/	1·5	1·0	2·0	2·4
30m	1·2	3·6	0·2	0·17	1·3	/	/
50m	0·5	/	/	/	/	0·5	3·5
100m	0·2	3·1	/	0·02	1·4	0·6	3·7
200m	0·2	2·8	0·3	0·01	1·7	0·8	4·3
500m	/	2·3	0·4	/	/	/	4·7

FIGURE 1



The horizontal standard deviation due to turbulence, σ_{y_t}, as a function of distance in each Pasquill category

FIGURE 2: SMUT FALL SPEED SPECTRUM

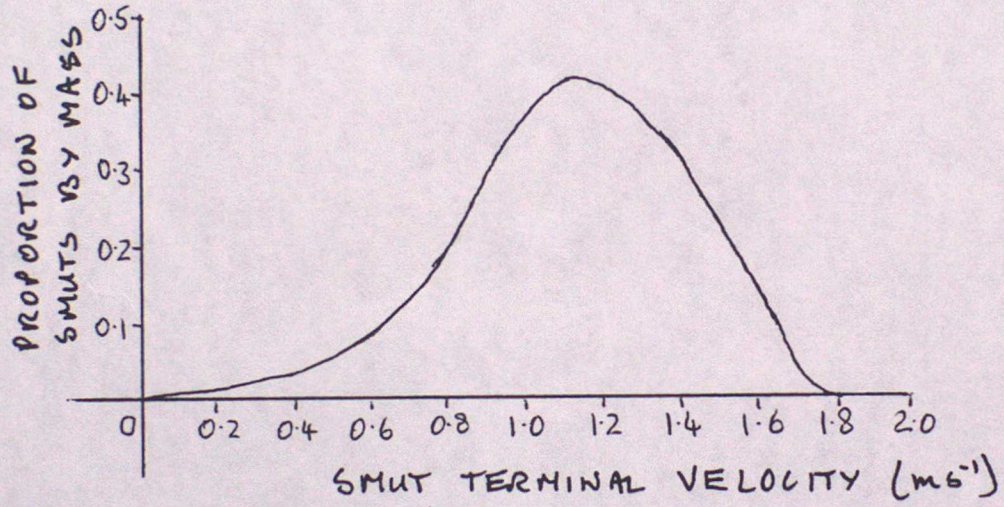


FIGURE 3 : THE RELATIONSHIP BETWEEN THE WIND SPEED AND THE SPEED OF THE FLAME FRONT.

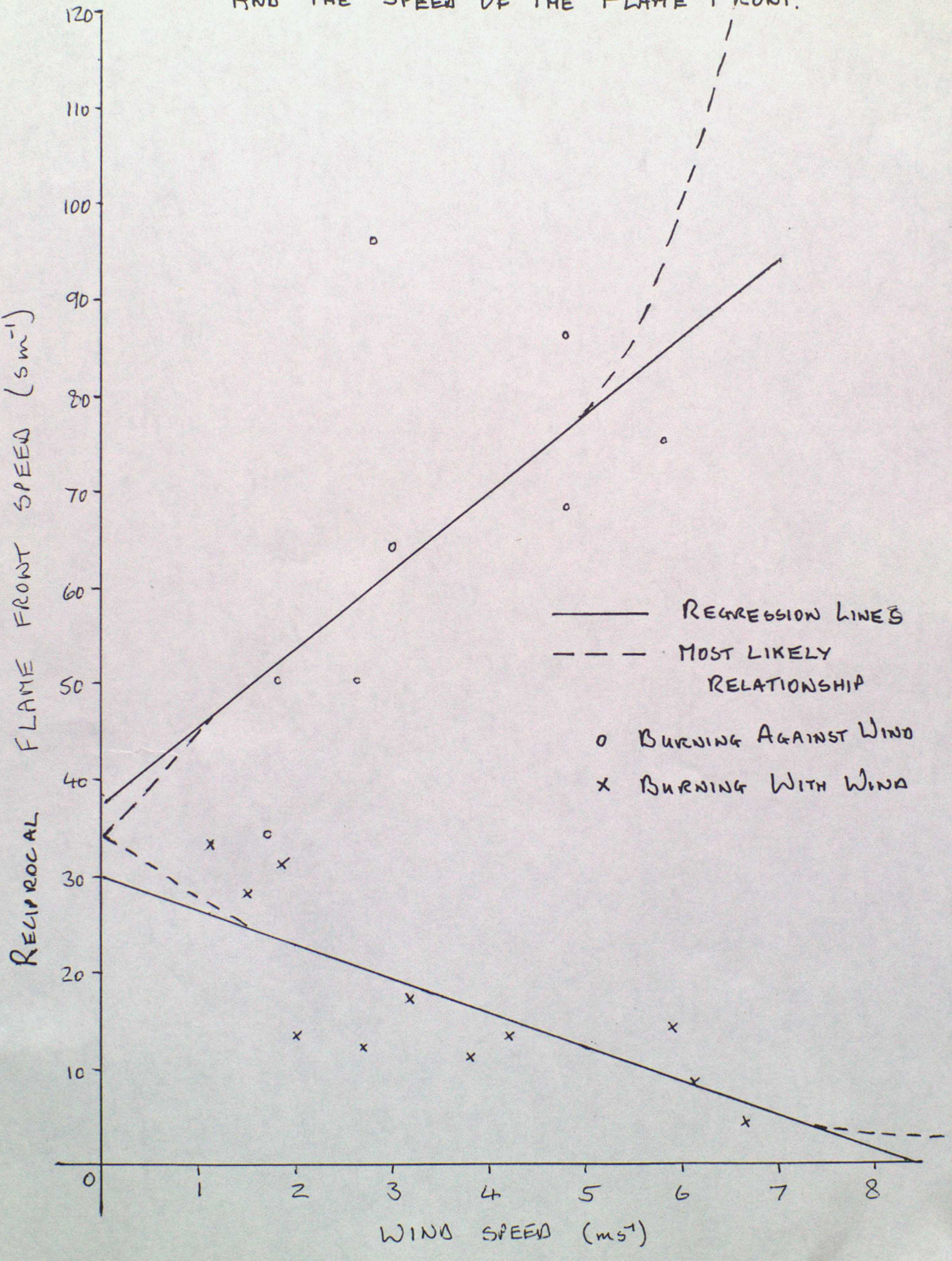


FIGURE 4: CONTOURS OF SMUT DEPOSITION DENSITY DOWNWIND FROM A BURN MADE AGAINST THE WIND.

SMUT OUTPUT: 5 KG PER HECTARE

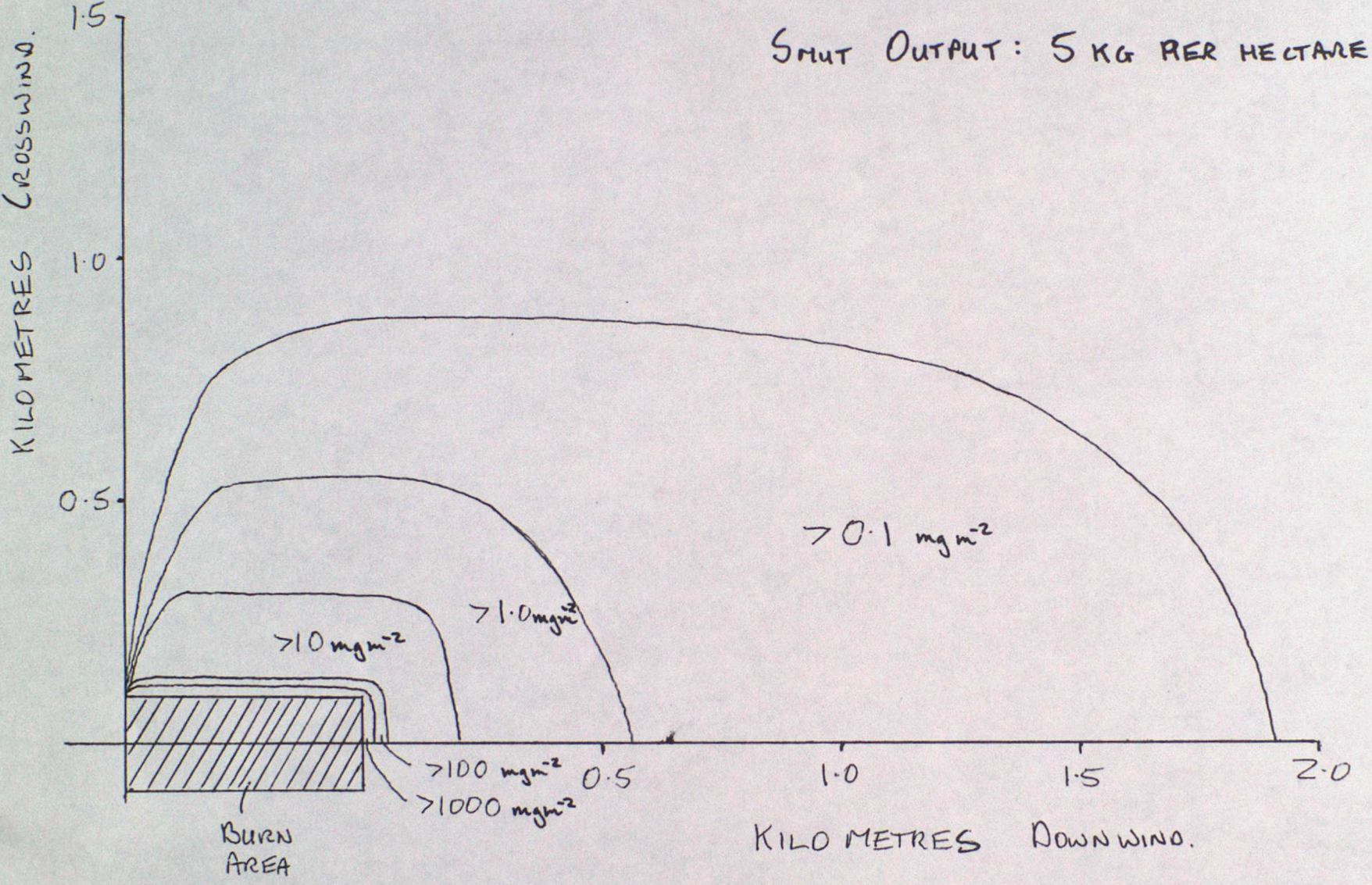


FIGURE 5: CONTOURS OF SMUT DEPOSITION DENSITY DOWNWIND FROM A BURN MADE WITH THE WIND

SMUT OUTPUT: 5 KG PER HECTARE

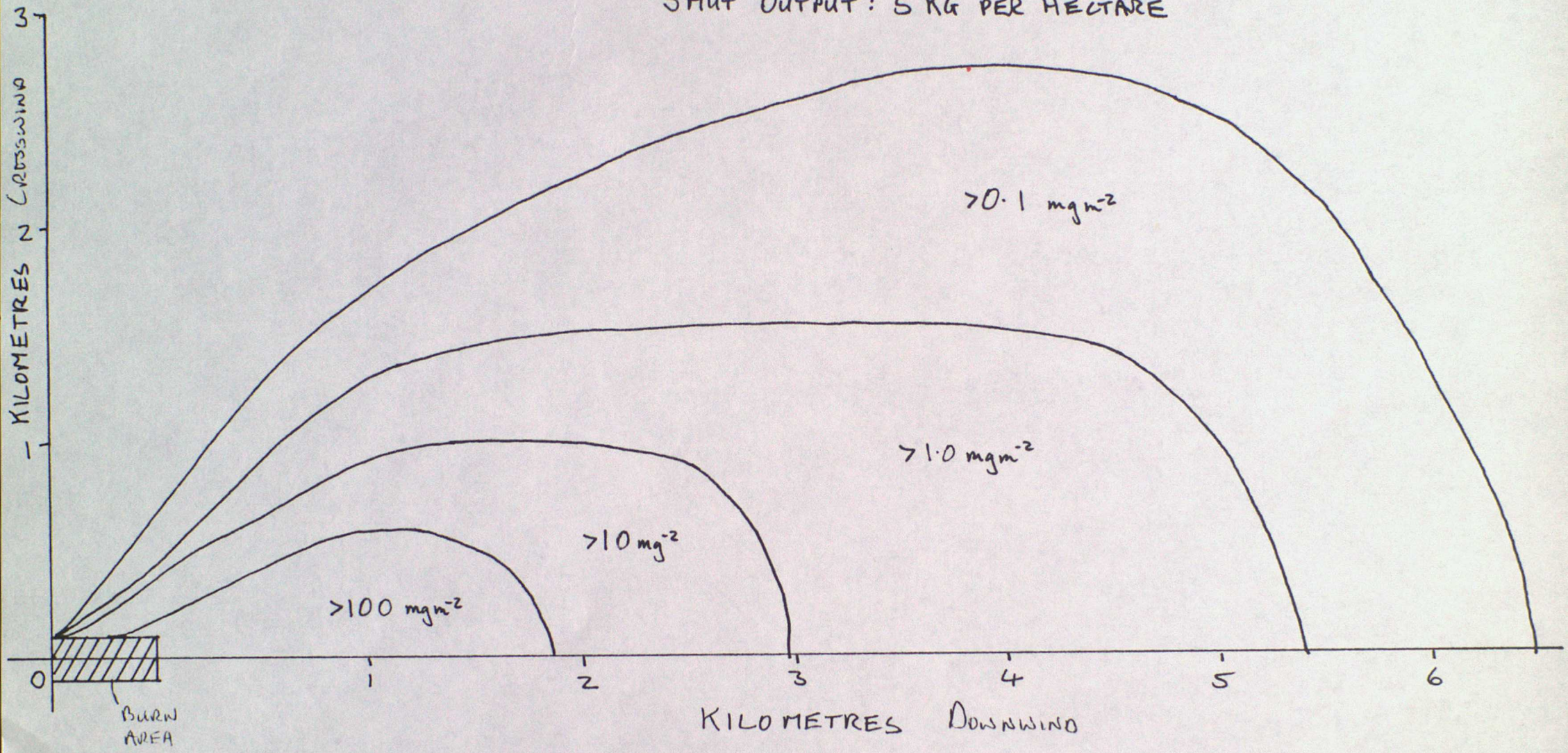


FIGURE 6: CONTOURS OF SMUT DEPOSITION DENSITY DOWNWIND FROM A BURN MADE ACROSS THE WIND.

SMUT OUTPUT: 5KG PER HECTARE

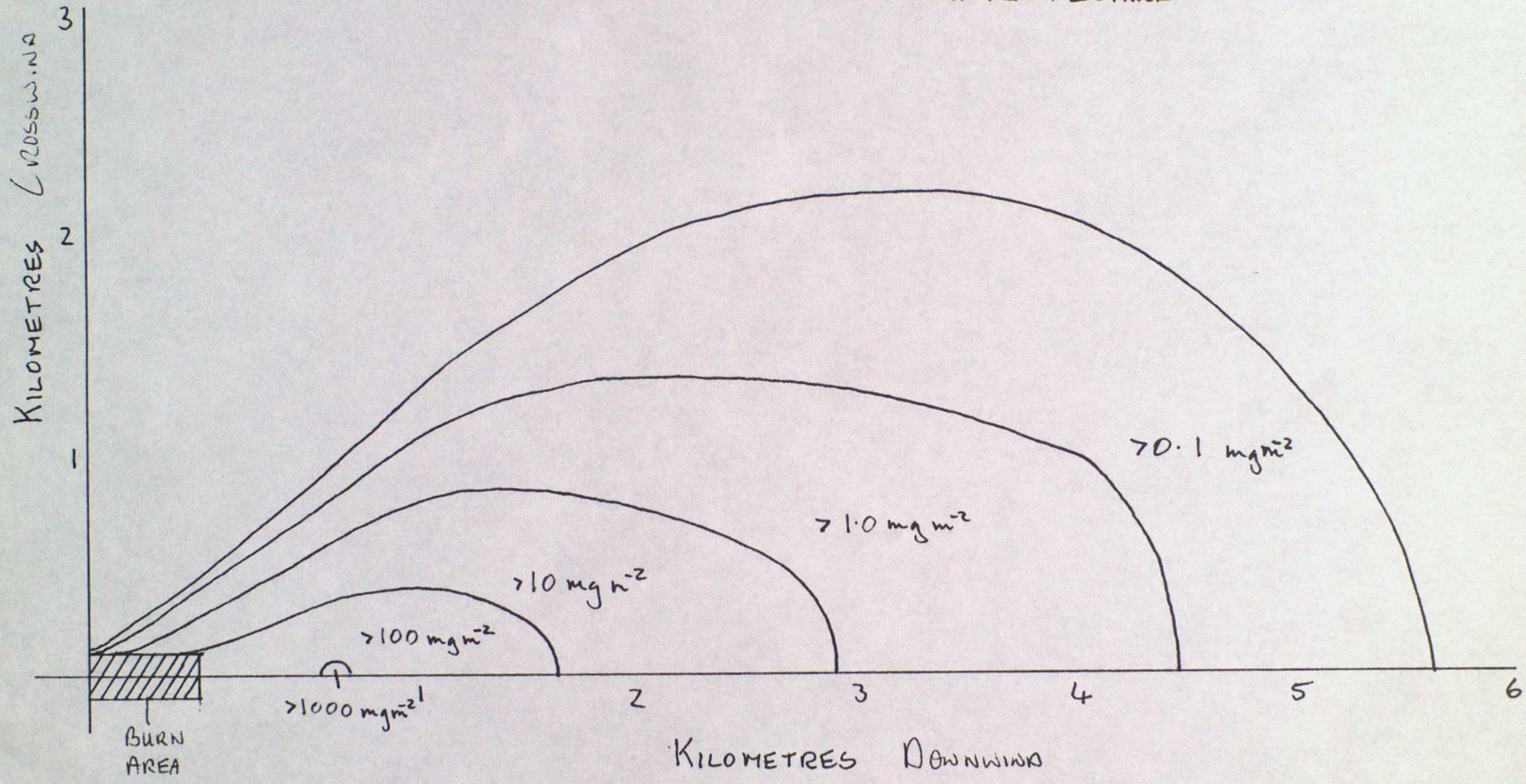
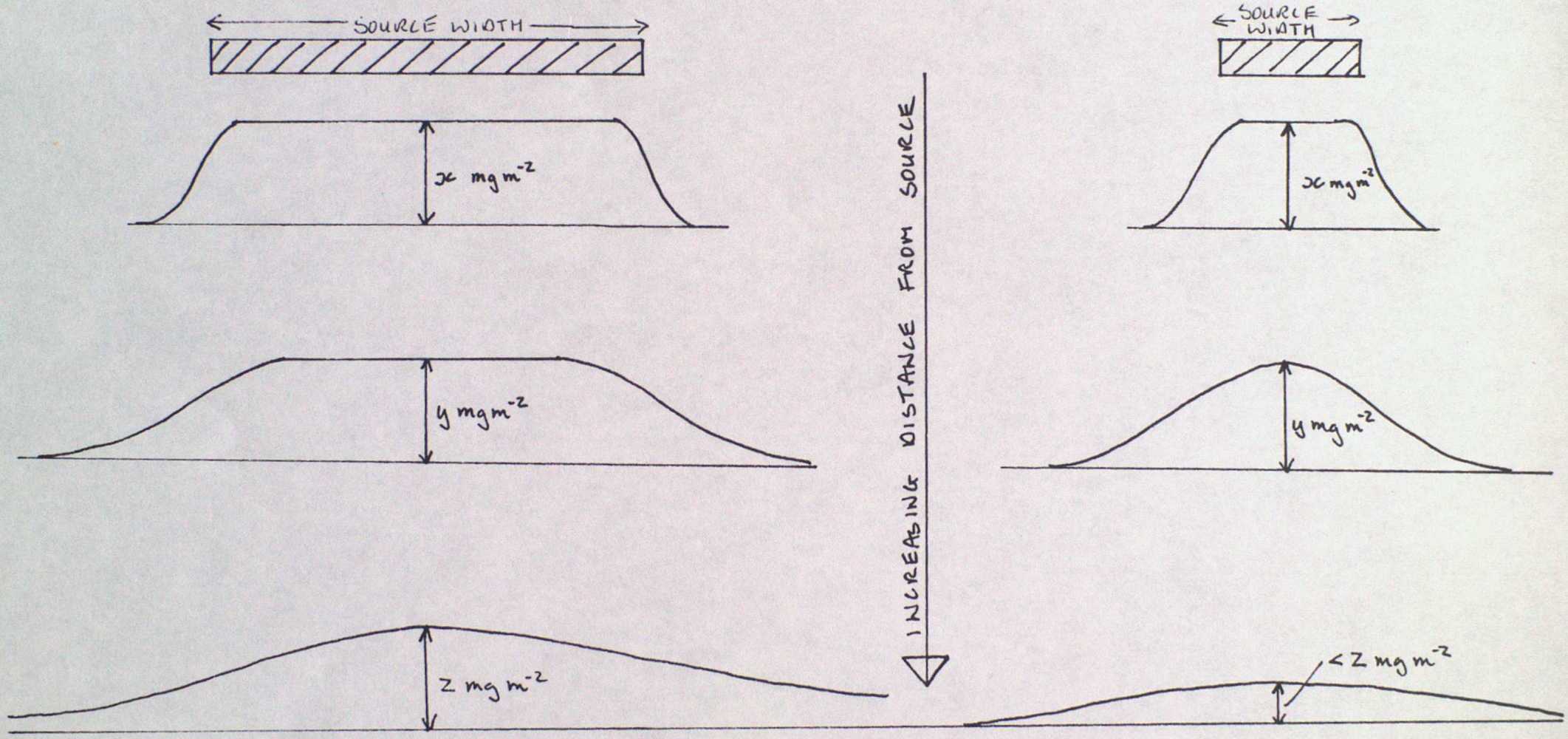


FIGURE 7: CROSS SECTIONS OF SMUT DEPOSITION DENSITIES DOWNWIND FROM SOURCES OF DIFFERENT LENGTH



APPENDIX 1 - Brief Descriptions of the 1984 Field Trial Burns

201 A field of spread wheat straw with its long dimension perpendicular to the wind. The burn commenced with back burning at the downwind field edge, but in the strong breeze the fire often went out. The fire was then taken down the field sides and across the upwind edge, to burn most of the field with the wind.

202 A field of barley stubble with the long dimension parallel to the wind. The burn started with backburning at the upwind edge and was then taken slowly up the long side. This meant that most of the field was burnt in a pseudo-across wind fashion.

203 An almost square field burnt in about four strips all at once, with the wind. So a very fast burn, being almost complete after fifteen minutes. The field contained a mixture of chopped and spread wheat straw.

204 A square field containing chopped wheat straw. After initial backburning half the field was burnt in strips with the wind followed by some backburning. The remaining half of the field was allowed to burn with the wind.

205 A field of spread wheat straw with the long dimension perpendicular to the wind. The sampled part of the burn was made entirely against the wind.

208 An elongated field of damp chopped straw burnt mainly with the wind in two sections. The wind blew roughly perpendicular to the long dimension.

215 A large 50 hectare square field of spread wheat straw. The downwind edge was backburnt throughout the two hour long burn. The rest of the field was burnt across the wind, which was the strongest of all the burns at 6 ms^{-1}.